PROCESSING, FABRICATION, AND DEMONSTRATION OF HTS INTEGRATED MICROWAVE CIRCUITS

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Westinghouse Electric Corporation
Science & Technology Center
1310 Beulah Road
Pittsburgh, PA 15235-5098

Program Manager
Dr. G. R. Wagner

Prepared for:

Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217-5000

Project Manager
Dr. W. A. Smith

R&D STATUS REPORT

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Principal Investigator: G. R. Wagner

Telephone No.: (412) 256-1436

Short Title of Work: Processing, Fabrication, and Demonstration of HTS Integrated Microwave Circuits

Reporting Period: 10/26/92 to 1/24/93

DESCRIPTION OF PROGRESS

TASKS 1.0 and 2.1: COMPARATIVE TECHNOLOGY ASSESSMENT AND INTEGRATED SUBSYSTEM SPECIFICATIONS

This task is essentially complete, but we are continuing to monitor progress in other technologies as they relate to the goals of this program.

TASK 2.1: INTEGRATED SUBSYSTEM SPECIFICATIONS

Work is in progress to determine the dynamic range of superconducting filters by studying their noise and power handling characteristics. The goal is to establish their usefulness in receiver front-end applications. The thermal noise figure of HTS filters and its effect on a filter-low-noise-amplifier chain are being examined. Calculations of the noise figures for the filter alone and for the filter-amplifier chain, are shown as a function of filter loss in Figures 1 and 2, respectively. Notice that, for cooled passive devices, the noise figure is lower than the insertion loss.

The noise figure of an HTS filter will be measured in the next quarter.

Measurements at 77K and 20K of the power handling capability of an HTS filter are in progress and will be completed next quarter.

TASK 2.2: FUNCTIONAL COMPONENT AND SUBSYSTEM DESIGN, FABRICATION AND TESTING

Filterbanks

The fabrication and packaging work reported here is responsible for progress made in the parallel HTSSE-II program sponsored by NRL. Filterbanks and delay lines pertaining to the HTSSE-II program were used as test vehicles for the technology developed in this ONR/DARPA program and prototypes resulting from that work will be delivered to NRL.

NOISE FIGURE OF HTS FILTERS

$$F = 1 + (L - 1)\,\frac{T}{290}$$

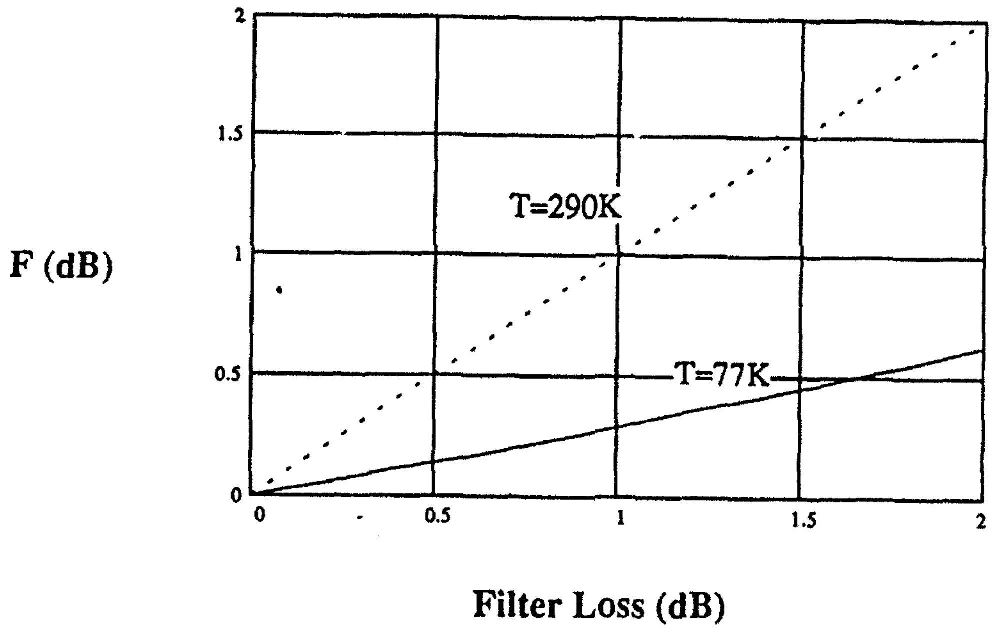

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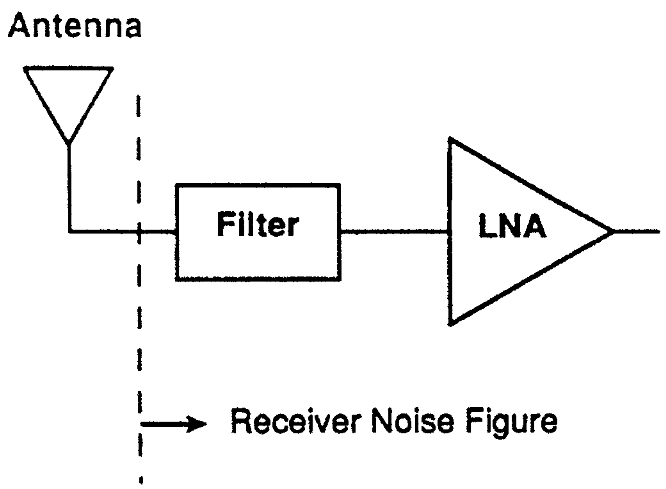
Figure 1. Noise figure calculation for filters at room temperature and 77K as a function of filter loss.

NOISE FIGURE OF RECEIVER FRONT-END



The higher the LNA quality, the more advantageous a superconducting filter becomes

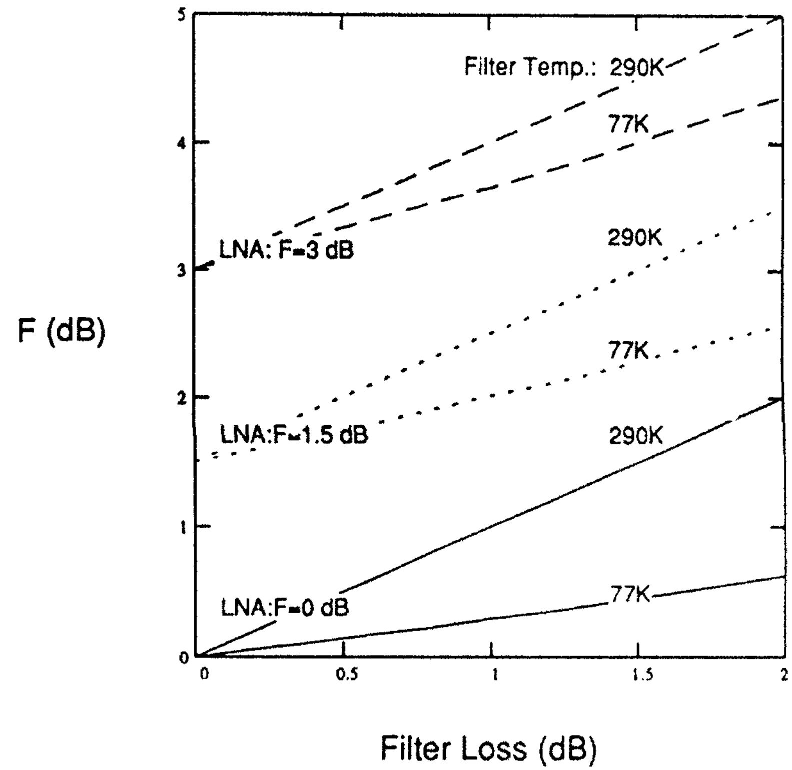


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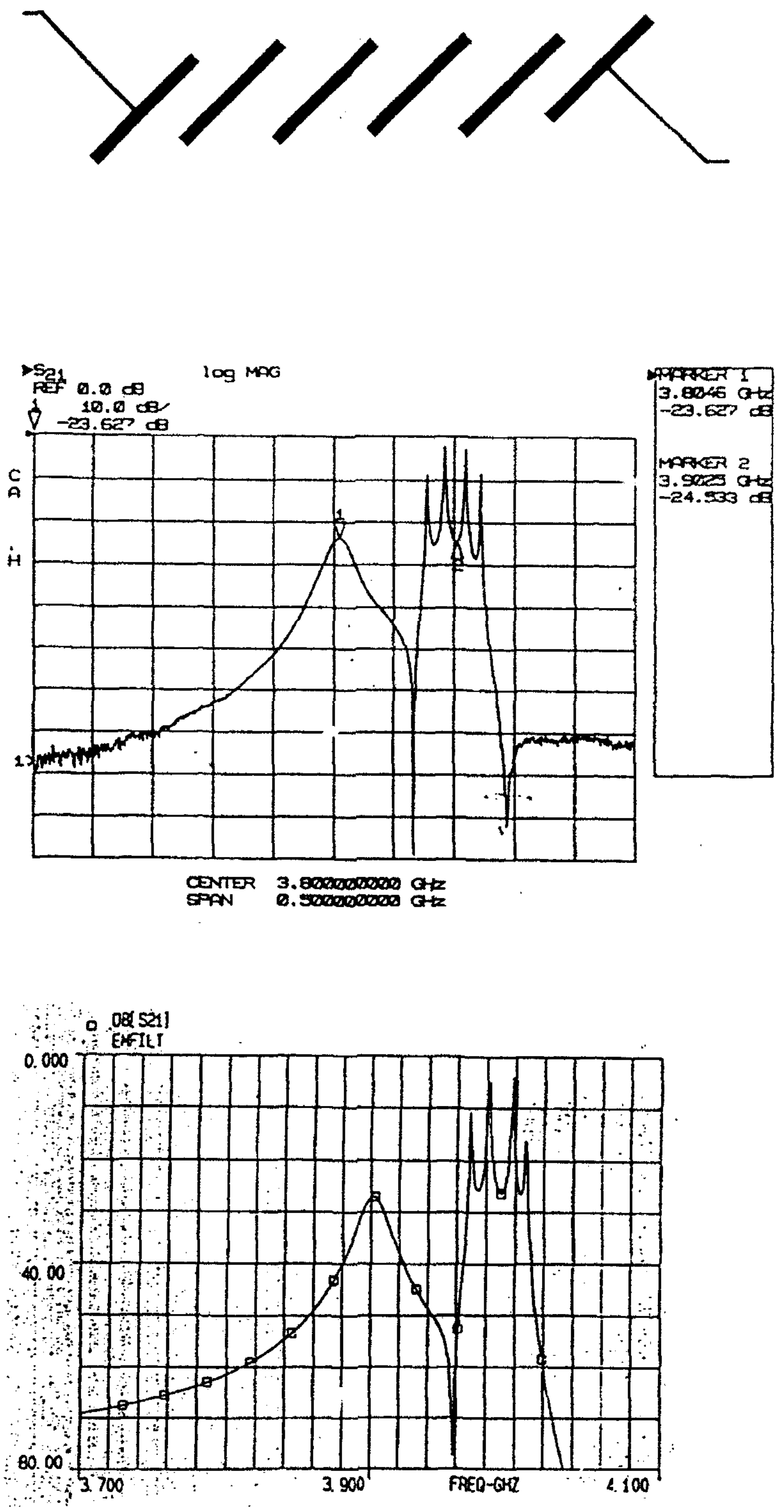
Figure 2. Calculated noise figure of a filter-amplifier chain as a function of filter loss.

The filter packaging and fabrication concepts developed in this program were tested during this reporting period with two different filters designed for the HTSSE-II program, namely, six-pole and four-pole Chebychev filters. Their configurations, measured results, and simulations using the electromagnetic field analysis software Sonnet are shown in Figures 3 and 4, respectively. As can be seen from these figures, the results agree well with the simulations. Both filters were designed using the Touchstone software from EEsof Corp. The output from Touchstone for both filters had near-ideal Chebychev characteristics. The six-pole filter, however, had input/output tee-junction taps into the first and last resonators, respectively, which were not designed accurately by Touchstone due to the high dielectric constant of the lanthanum aluminate substrates. The four-pole filter, which uses quarter-wave coupled sections as the input/output transformers, has a response closer to ideal, as design showed. Nevertheless, its response is asymmetric and has no more than a 60 dB out-of-band rejection near the lower skirt, indicating a sub-optimal performance from the design software used.

One of the goals of this program is to make filters and delay lines to exact specifications and in a repeatable fashion. However, as the foregoing results and simulations show, a proper comparison between measurements and design cannot be limited to the output from standard microwave design software. It must include more sophisticated design techniques and a direct comparison with an electromagnetic simulation of the fabricated filter structure. We will be studying this problem in the next few months to determine the degree of design improvements required and the filter structures for which it is needed most.

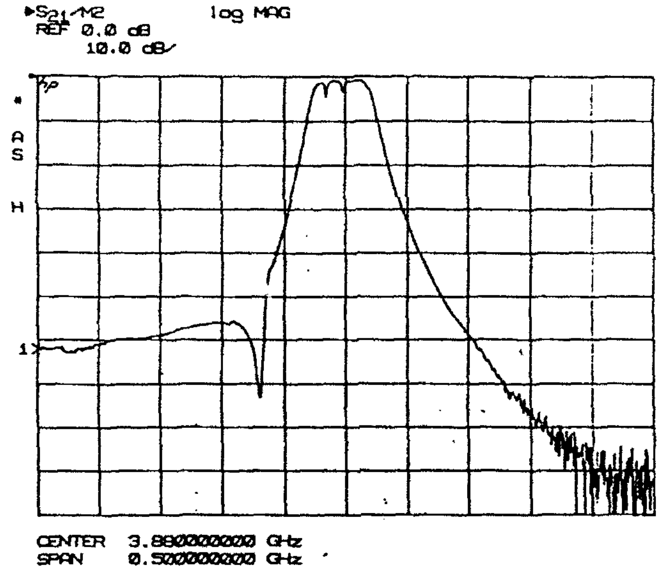
Notwithstanding the inadequate design tools available today, of importance here is the validation of our packaging approach for filters. The four-pole filter will be used in the fabrication of the four channel filterbank for HTSSE-II. Notice that a high out-of-band rejection was achieved for both filters, a criterion that must be met by a good microwave package.

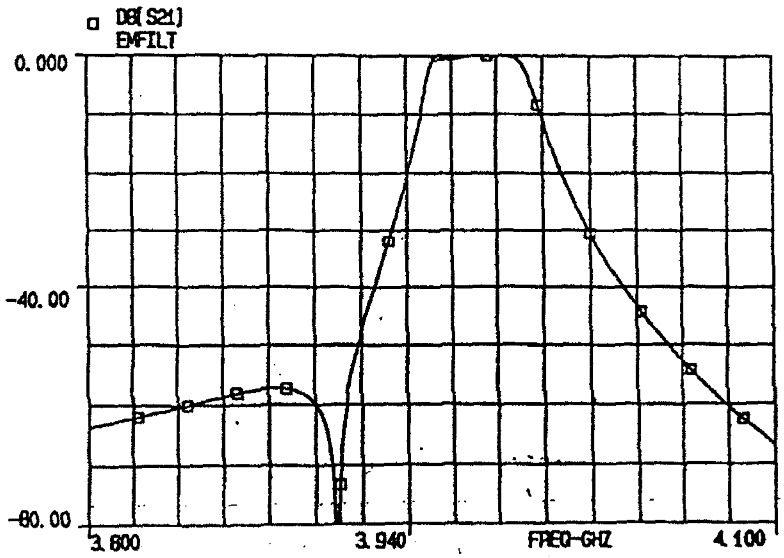


Sonnet analysis courtesy of G. Wray, EEsof

Figure 3. **Structure of a six-pole Chebychev filter designed using Touchstone (top); passband measurement (middle) and analysis (bottom).**

Design center frequency:: 3901 MHz





Sonnet analysis courtesy of G. Wray, EEsof

Figure 4. Structure of a four-pole Chebychev filter designed using Touchstone (top); passband measurement (middle) and analysis (bottom).

Delay Lines

Using internal funding, a validation of our stripline packaging approach was conducted using a delay line made with niobium on a $LaAlO_3$ substrate and a YBCO top ground plane. The measured results are shown in Figure 5, where the plot on the left is the measured insertion loss between 2 and 6 GHz. The plot on the right is the time-domain reflection coefficient in linear magnitude when the output port is terminated in a short circuit. It shows that the delay is 20 nS (25 nS design) and that there are two discontinuities in the middle of the line. Their cause is now being explored. They are probably due to air gaps between the two substrates that form the stripline configuration. The delay line insertion loss oscillates between almost 0 dB and 5 dB for most of the 4 GHz band. The oscillations are due to the discontinuities alluded to above.

Since the delay line is designed as a 50-Ω line, the stripline width is only 22 μm (for 10-mil thick $LaAlO_3$ wafers). The line length is 155 cm. This is very demanding on our YBCO films and our fabrication techniques on our best films are being optimized for this task.

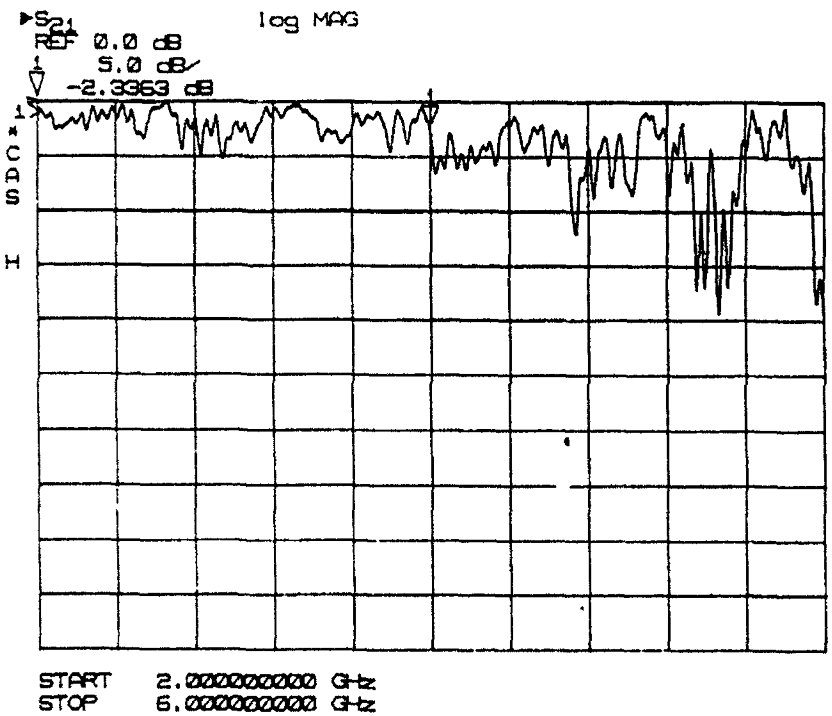
TASK 3.1: PVD MULTILAYER FILM FABRICATION

The two tasks scheduled for this reporting period required delivery of YBCO films on both sides of two-inch diameter substrates to Task 2.2, and development of a multilayer deposition capability on four-inch wafers.

YBCO films on two-inch diameter substrates were prepared for filterbank channels (0.020-inch thick wafers) and delay lines (0.010-inch thick wafers) at a rate commensurate with the low level of expenditure on fabrication and testing during the quarter. Spot checks performed on the rf surface resistance of films for filterbanks indicated that all films met the requirement for $R_S \leq 0.5$ mΩ at 77K and 10 GHz. The only critical variable identified in the previous quarter that could result in degraded properties is the substrate temperature during growth, which was maintained at $\geq 750^\circ$C.

Nb DELAY LINE

Insertion Loss vs. Frequency



Reflection at Port 1, Short at Port 2

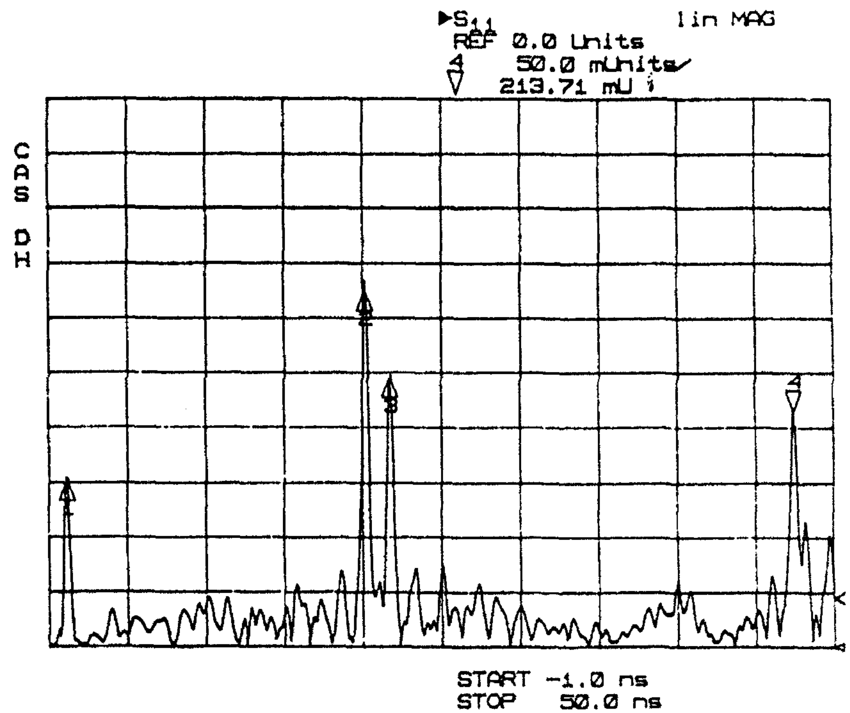


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Figure 5. Measured results on a Nb delay line fabricated using internal funding to validate the stripline packaging approach developed in this program.

During this reporting period, a less-easily controlled deposition variable was identified which stemmed from inhomogeneity of YBCO sputtering targets. Each good target produced approximately 16 films 0.4 μm thick. However, when inhomogeneous areas were present, the plasma would concentrate at a few points on the target surface and rapidly drill holes all the way through. After consulting with the two target vendors, the solution appears to be in the use of more expensive and higher density targets made from co-precipitated powders in place of powders made from solid-state reactions and grindings.

Two-inch diameter YBCO films produced for delay lines were grown under the same condition and in the same chamber as the films for filters. However, R_S was not measured to minimize the possibility of dust or debris contaminating the surface. In contrast to the relatively wide lines patterned for 50 Ω microstrip on 0.020-inch thick substrates, the 50 Ω stripline configuration used for delay lines requires a line 22 μm wide by 155 cm long uninterrupted by dust or debris. By minimizing handling outside of the clean room where delay lines are patterned, the number of dust particles has been kept sufficiently low (3 to 5 per two-inch wafer) that the entire spiral can be aligned to avoid them.

Progress in the development of YBCO-coated four-inch wafers began with delivery at the end of December of a new sputtering chamber built to a Westinghouse design by Nordiko Ltd., which can accommodate two-, three-, or four-inch wafers. The most important part of the chamber is the substrate heater which must hold the substrate at 750 °C during deposition without direct contact. The quartz lamp design supplies 2.6 kW of power and the desired growth temperature was obtained. In contrast, the non-contact heaters used to produce two-inch YBCO films provide 550 W. The initial YBCO films produced on two-inch wafers in the new chamber had high T_Cs but also had high R_S. Elastomer seals in the vicinity of the substrate heater were getting too hot and contaminating the sputter gas. Recently, new thermal shields have been added to better focus heat on the substrate and away from the nearest elastomer seals. They reduced the

duty cycle of the heater needed to maintain the desired substrate temperature from 70% to <50%.

TASK 3.2: MOCVD MULTILAYER FILM FABRICATION

Work under this task was performed at EMCORE on YBCO film growth, at Northwestern University on the development of new Ba precursors for YBCO and growth of epitaxial insulating films, and at Westinghouse STC where measurements were made of the vapor pressure of precursors and rf surface resistance of YBCO films.

Two batches of Ba precursors were delivered to EMCORE by the group at Northwestern University. The first was a purified $Ba(thd)_2$, the standard precursor which can only be obtained commercially in a low-purity form. The bubbler temperature had to be raised by 10-15°C to obtain the same vapor pressure with the purified material that had been obtained with the commercial source. Despite the apparent difference in the precursor, there was no observable change in film properties in switching to the high-purity source. The second precursor batch was a $Ba(hfa)_2$-tetraglyme. No films have yet been grown with it.

EMCORE has prepared a sample holder for coating both sides of two-inch wafers. It is large enough that a similar holder would accommodate a four-inch wafer. Work on depositing on the second side of wafers will begin in the coming quarter.

Sputtered YBCO films were sent from Westinghouse to Northwestern for growth of epitaxial insulators by MOCVD. High quality insulating films of $SrAl_{0.5}Ta_{0.5}O_3$ (SAT), $YAlO_3$, and $PrGaO_3$ grown at high deposition temperatures (≥900°C) directly on single-crystal substrates could not be grown on YBCO due to chemical reaction with the YBCO underlayer. The future direction of this work is plasma-assisted MOCVD where reductions in the required growth temperature have been obtained in other material systems including YBCO.

TASK 3.3: RF CHARACTERIZATION OF FILM PROPERTIES

A copper cavity measurement set up for two-inch diameter wafers (end-wall replacement technique) was used for spot checks of the films to be patterned for filters. Values of $R_S \leq 0.5$ mΩ at 77K and 10 GHz were found indicating that the films were qualified for device fabrication. A parallel-plate measurement technique for 1 cm^2 and $1/4 \times 1/2$ in^2 samples was used for evaluation of MOCVD grown films and as a check on the calibration of the copper cavity measurement. Some improvements in the parallel plate measurement were instituted to improve sensitivity, which was limited by losses in the walls of the package. The teflon spacer was replaced by a 0.001 inch sapphire spacer to better confine the rf fields, and the package volume was increased with Kapton spacers used to keep the parallel films in place. The sensitivity is now $<< 0.5$ mΩ.

PROBLEMS ENCOUNTERED AND/OR ANTICIPATED

Although the start date of this program was July 24, 1991 with the approval of anticipatory spending, the contract was not signed until September 30, 1991 when the first increment of funding was received. Our current allocation is sufficient for the first year of effort, but is designated to cover the work through October 31, 1992. The work effort was slowed at DARPA's request to stretch the FY92 funding through 12/31/92. However, no FY93 funds have been received and are not anticipated before April 1, 1993. These funding limitations will place the program six months behind schedule.

FISCAL STATUS

Amount currently provided	$1,600,000
Expenditures and commitments through 1/24/93:	1,720,158 *
Funds required to complete:	3,769,203
FY93 funds required:	1,827,386

*Includes $145,946 committed to subcontractors.